Topological insulator nanoparticles – material with prospect for photo-thermal applications

Belec B[(1)*], Kostevšek N[(2)], Pelle GD[(2)], Gardonio S[(1)], Fanetti M[(1)], Valant M[(1)]

(1) Materials Research Laboratory, University of Nova Gorica, Ajdovščina, Slovenia
(2) Department for Nanostructured materials, Jožef Stefan Institute, Ljubljana, Slovenia

*Corresponding author's email: blaz.belec@ung.si

Bismuth selenide (Bi_2Se_3) is one of the most investigated topological insulators (TI). Due to its topological surfaces states (TSS), it displays unique electronic and optical properties [1, 2]. Unlike conventional surface states, TSS are robust and unaffected by almost any type of non-magnetic impurities due to the combined effect of the time-reversal symmetry and spin-orbit coupling. However, TSS are stable up to a critical concentration of dopants [3, 4], and as we propose in our study, they can also be disturbed by an organic layer coated on the surface of TI nanoparticles. Namely, the adsorbent-free Bi_2Se_3 nanoparticles display localized surface plasmon resonance (LSPR) due to electronic bulks states and their peculiar TSS, while the coated counterparts do not [5].

The existence of LSPR is also a reason that the TI nanoparticles display a photo-thermal effect [6, 7]. A number of publications on the photo-thermal effect of the TI nanoparticles is scarce. Additionally, all the research was conducted on the nanoparticles, synthesized in presence of organic solvents and/or surfactants, or they were deliberately coated with organic molecules [6, 8-10]. Since the organic molecules affect the TSS, the true photo-thermal effect (the real ΔT induced by illumination) of the TI nanoparticles has not been measured yet.

We recently developed a hydrothermal method for synthesis of the adsorbent-free Bi_2Se_3 nanoparticles [5]. According to a UV-vis spectroscopy, the particles display peak, which corresponds to the LSPR. The photo-thermal experiment reveals that they heat when illuminated with a laser of 808 nm [11]. Since they are free of any adsorbents, we have measured their true photo-thermal effect.

The electronic surface properties of TI and consequently their photo thermal effect can be tuned or even enhanced by shifting the position of the Fermi level. This can be achieved by doping the nanoparticles, but only up to the certain concentration. Till now, there is no research on doping the Bi_2Se_3 nanoparticles, and how this effect their optical and photo-thermal properties [3, 4].

With our developed hydrothermal method, we have successfully synthesized In- and Cr-doped Bi_2Se_3 nanoparticles ($Bi_{2-x}M_xSe_3$, M = In^{3+}, Cr^{3+}). With the UV-vis spectroscopy we have confirmed the presence of the LSPR peaks in all prepared samples showing the TSS are still present. The photo-thermal experiment (808 nm, 3 W/cm^2, 5 min) revealed that the In- and Cr-doped Bi_2Se_3 particles heat under the irradiation. The heating effect was similar or even higher than in the reported studies [6, 8-10]. Such doped TI nanoparticles have a potential to be further used, for instance in bio-medical applications. The TI nanoparticles can be coated with a thin film of porous amorphous silica, which gave us the base for numerous possibilities to attach different targeting molecules. As we recently demonstrated, a thin silica layer does not interfere with TSS and such coated particles still heat under the irradiation. Moreover, ΔT of silica-coated Bi_2Se_3 was higher compared to uncoated one [11].

References

[1] M.Z. Hasan, C.L. Kane, Colloquium: Topological insulators. Rev. Mod. Phys. 82 (2010) 3045-3067.

[2] W. Tian, W. Yu, J. Shi, Y. Wang, The Property, Preparation and Application of Topological Insulators: A Review. Materials 10 (2017).

[3] J. Sánchez-Barriga, I. Aguilera, L. V. Yashina, D.Y. Tsukanova, F. Freyse, A.N. Chaika, C. Callaert, A.M. Abakumov, J. Hadermann, A. Varykhalov, E.D.L. Rienks, G. Bihlmayer, S. Blügel, O. Rader, Anomalous behavior of the electronic structure of (Bi1−xInx)2Se3 Across the Quantum Phase Transition From Topological to Trivial Insulator. Phys. Rev. B. 98 (2018).

[4] J. Moon, N. Koirala, M. Salehi, W. Zhang, W. Wu, S. Oh, Solution to the Hole-Doping Problem and Tunable Quantum Hall Effect in Bi2Se3 Thin Films. Nano Lett. 18 (2018) 820-826.

[5] B Belec, K. Ferfolja, T. Goršak, N. Kostevšek, S. Gardonio, M. Fanetti, M. Valant, Inherent Surface Properties of Adsorbent-Free Ultrathin Bi2Se3 Topological Insulator Platelets. Sci. Rep. 9 (2019)119057-190579.

[6] J. Guozhi, W. Peng, Z. Yanbang, C. Kai, Localized surface plasmon enhanced photothermal conversion in Bi2Se3 topological insulator nanoflowers. Sci. Rep. 6 (2016) 25884.

[7] Y. Zhao, A. Dunn, J. Lin, D. Shi, D. Photothermal Effect of Nanomaterials for Efficient Energy Applications. Micro and Nano Tech (2015) 415-434. 10.1016/b978-0-12-814497-8.00013-8.

[8] Z. Li, Y. Hu, K.A. Howard, T. Jiang, X. Fan, Z. Miao, Y. Sun, F. Besenbacher, M. Yu, Multifunctional Bismuth Selenide Nanocomposites for Antitumor Thermo-Chemotherapy and Imaging. ACS Nano 10 (2016) 984-997.

[9] Z. Li, J. Liu, Y. Hu, K.A. Howard, Z. Li, X. Fan, M. Chang, Y. Sun, F. Besenbacher, C. Chen, M. Yu, Multimodal Imaging-Guided Antitumor Photothermal Therapy and Drug Delivery Using Bismuth Selenide Spherical Sponge. ACS Nano 10 (2016) 9646-9658.

[10] J. Li, F. Jiang, B. Yang, X.R. Song, Y. Liu, H.H. Yang, D.R. Cao, W.R. Shi, G.N. Chen, Topological Insulator Bismuth Selenide as a Theranostic Platform for Simultaneous Cancer Imaging and Therapy. Sci. Rep. 3 (2013) 1998.

[11] B. Belec, N. Kostevšek, S. Nemec, S. Kralj, S. Gardonio, M. Fanetti, M. Valant, Silica coated Bi2Se3 topological insulator nanoplatelets: the way of making them colloidally stable but preserving their optical properties. In 27th Annual Meeting of the Slovenian Chemical Sociedy Portorož (2021) pp 56.